Space-time Analysis of the Urban-Rural Gradient in the Metropolitan Area of Madrid and its surroundings (Guadalajara, Cuenca and Toledo)

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Abstract

According to UN provisions in the period from 2007 to 2050 world population will grow up to 9200 million people. In fact, for the first time in history, in the year 2008 world urban population became higher than rural population. The increase of urban areas and their transport infrastructures has influenced agricultural land use due to their irreversible change, especially when they remain as periurban vacant land, losing their character and identity. In the Europe of the nineties, the traditional urban-rural gradient, characterized by a neat contact between both land types, has become so complex that it has change to a gradient in which it is difficult to separate urban and rural land uses. [Antrop 2004]. A literature review has been made on methodologies used for the urban-rural gradient analysis. One of these methodologies was selected that integrates ecological characterization based on the use of spatial metrics and geographical characterization based on spatial components. Cartographical sources used were Corine Land Cover at 1: 100000 scale and the Spanish Land Use Information System at 1:25000 scale. Urban-rural gradient paradigm is an analysis methodology, coming from landscape ecology, which enables to investigate how urbanization provokes changes in ecological patterns and processes into landscape. [Hahs and McDonnell 2006].The present research adapt this methodology to study the urban-rural gradient in the outskirts of Madrid, Toledo and Guadalajara. Both scales (1:25000 and 1: 100000) were simultaneously used to reach the next objectives: 1) Analysis of landscape pattern dynamics in relation to distance to the town centre and major infrastructures. 2) Analysis of landscape pattern dynamics in the fringe of protected areas. The paper presents a new approach to the urban-rural relationship which allows better planning and management of urban areas.

1. Introduction

According to forecasts by the UN in the period between 2007 and 2050, world population will rise to 9,200 million people, representing an increase of 37% over 2007. Urban areas contain 6,400 million people increasing from 49% in 2007 to 70%. In fact in 2008 for the first time in history the urban population equaled the rural population worldwide [UN]. The increase in urban areas and associated transport infrastructure has affected irreversibly to agricultural land use because of its irreversible transformation and its amorphization–trivialization, when they remain as areas of vacant land in suburban areas, losing its character and identity. [Frondoni et al. 2011]. In Europe since the early nineties, with the adoption of the diffuse growth pattern, the urban-rural gradient characterized by a net contact between land uses has become more complex so that the contact has been transformed into a gradient along which it is difficult to separate urban uses from rural areas since it is highly fragmented and heterogeneous. [Antrop 2004]. The urban-rural gradient paradigm analysis is a methodology of landscape ecology that allows to investigate how urbanization leads to changes in ecological patterns and processes across the landscape, and can be functional or structural analysis. [Hahs and McDonnell 2006]. The research focuses on the study of urban-rural gradient in the environment of the cities of Madrid, Toledo and Guadalajara, but the analysis is not limited by the imposition of administrative boundaries in order to highlight the driving forces that have led to current landscape patterns.

1.1. Study Area

From the 90's, the Madrid metropolitan area is superseded by the urbanization process affecting almost all of the Community of Madrid and has exceeded its administrative limits to Guadalajara and Toledo and to a lesser extent to Cuenca, Avila and Segovia. This territorial transformation has occurred with the development of transport infrastructure based on a radiocentric model (structured in radial arteries with their corresponding beltways) characteristic of the territorial structure of urban regions with high income. [Lopez de Lucio 2003]. The selected study area extends south of the border of urban land in the capital Madrid in 1990, comprises all the municipalities who contact Madrid with Castilla- La Mancha found in the catchment area of the capital, those forming the southern boundary of the area. [Junta de Comunidades de Castilla - La Mancha 2010]. Transcending administrative boundaries and to show how the distance and accessibility to the Spanish capital has influenced landscape patterns of the 16 years analyzed [Antrop 2004], the study area has been subdivided into four sectors delimited by the national radial roads that connect the capital Madrid and Barcelona to the northeast of the capital (Highway A-2), Valencia southeast of the capital (Highway A-3), with Cordoba in the south (Highway A-4), southwest Toledo (Highway A-42) and Badajoz southwest of the capital (Highway A-5). The area covers 9,973 km^2 comprising 38% of the surface of Madrid and 9% of Castilla - La Mancha region, divided between the provinces of Toledo (30% of the province) Cuenca (3%) and Guadalajara (15%).

2. Material and Methods

We started from the database of CORINE Land Cover 1:100,000 scale, with a minimum size of polygons of 25 ha, in the three currently available reference years 1990 (CLC90) 2000 (CLC2000) and 2006 (CLC2006) and the databases of land use changes occurring during the period 1990 - 2000 (CLC1990-2000) and 2000 - 2006 (CLC2000-2006), with a minimum size of 5 ha polygon. The study area contains 31 kinds of land use of the 44 identified by the CORINE up to level 3. It has been made two successive hierarchical groups, depending on the degree of human intervention and level of globalization, resulting in 12 classes on the first level and three classes in the second, [Lörzing 2001] with the aim of analyzing the evolution of landscape patterns from a dynamic point of view, in terms of processes and mechanisms that cause these patterns [Bolòs Pla i Capdevila and Bovet 1992] and from a spatial point of view, through the use of landscape indicators [Frondoni, Mollo and Capotorti 2011]. Once the two maps for each year and grouping levels identified for each sector have been made, an intersection of them with the map containing the areas obtained around the edge of urban land in the capital of Madrid in 1990 is performed with an equidistance of 10 km between them. The maps in vector format have been made with the program ArcGis 10 and the landscape indicators with freeware software Fragstats 3.4 [McGarigal et al. 2002]

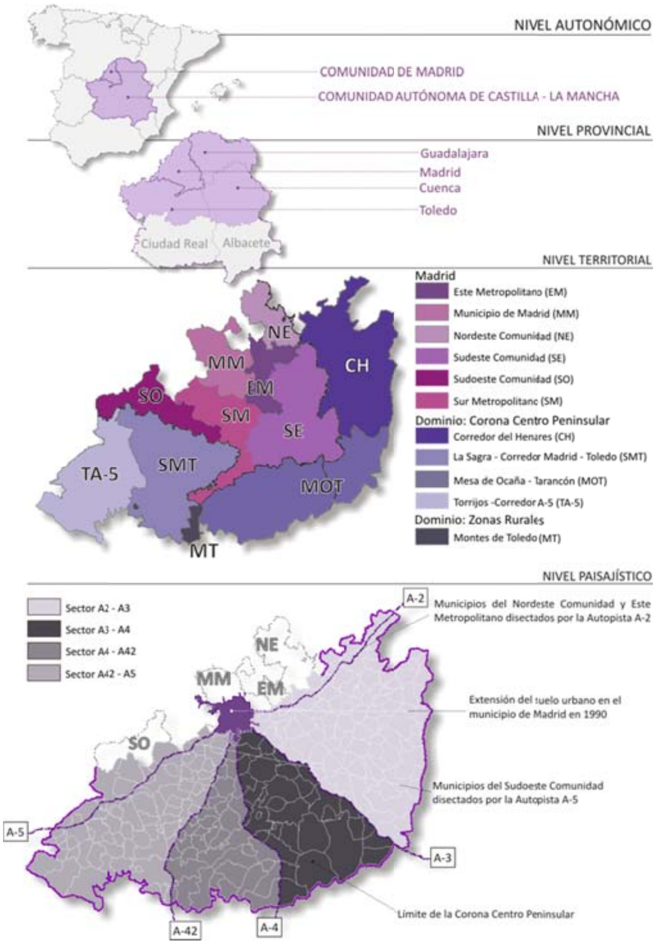

FIGURE 1: Study area

NATURAL LANDSCAPES		TRADITIONAL LANDSCAPES		RATIONAL LANDSCAPES	
FORESTS	3.1.1 3.1.2 3.1.3	***ARABLE LANDS***	2.1.1 2.1.2 2.4.1 2.4.2	***GREEN AREAS***	1.4.1 1.4.2
EMI-NATURAL AREAS	2.3.1 3.2.3 3.2.4 3.3.3 3.3.4	***PERMANENT CROPS***	2.2.1 2.2.2 2.2.3	***CONSTRUCTION SITES***	1.3.3.
WATER	4.1.1 5.1.1 5.1.2	***AGRO-FORESTRY AREAS***	2.4.3 2.4.4	***TRANSPORT UNITS***	1.2.2 1.2.4
				OTHER RATIONAL LANDSCAPES	1.3.1 1.3.2
				INDUSTRIAL OR COMMERCIAL UNITS	1.2.1
				URBAN FABRIC	1.1.1 1.1.2

NATURAL LANDSCAPE

FORESTS. 3.1.1. Broad-leaved forest. 3.1.2. Coniferous forest 3.1.3. Mixed forest

SEMI-NATURAL AREAS 2.3.1.Pastures.3.2.1. Natural grassland. 3.2.3. Sclerophyllous vegetation. 3.2.4. Transitional woodland shrub. 3.3.3. Sparsely vegetated areas.3.3.4. Burnt areas

WATER 4.1.1. Inland marshes. 5.1.1. Water courses. 5.1.2. Water bodies

TRADITIONAL LANDSCAPE

ARABLE LANDS 2.1.1 Non-irrigated arable land. 2.1.2. Permanently irrigated land. 2.4.1 Annual crops associated with permanent crops. 2.4.2. Complex cultivation

PERMANENT CROPS 2.2.1. Vineyards. 2.2.2. Fruit trees and berry plantations. 2.2.3. Olive groves

AGRO-FORESTRY AREAS 2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation. 2.4.4. Agro-forestry areas

RATIONAL LANDSCAPE

GREEN AREAS. 1.4.1. Green urban areas

. 1.4.2. Sport and leisure facilities 1.3.3.*CONSTRUCTION SITES*. *TRANSPORT UNITS* 1.2.2. Road and rail networks and associated land.1.2.4.Airports

OTHER RATIONAL LANDSCAPES 1.3.1 Mineral extraction sites

. 1.3.2 Dump sites

1.2.1. INDUSTRIAL or COMMERCIAL UNITS. *URBAN FABRIC* 1.1.1 Continuous urban fabric

. 1.1.2. Discontinuous urban fabric

TABLE 1: Hierarchical nomenclature

2.1. Dynamic Analysis

In order to identify whether there is a pattern of variation in the dynamic landscape gradient along the urban-rural, ultimately dependent on the distance to Madrid and its accessibility, the study has started from a transition matrix traditionally used in the analysis of changes in land use but with the following adjustments to the base map data and objectives. [Pontius Jr. et al. 2004]. Each row has scored class i in year 1 that turns into a class j of year 1+n, obtained from Database CLC changes CLC1990-2000 and CLC2000-2006. The result is the surface belonging to each category that suffers no change as the difference of the total area of category 1 and the losses suffered during the period 1 to 1+n. As in other traditionally used transition matrices, in this case the sum of the columns does not equal the total area of each class in year 2, due to the methodologies used in the production of databases of CORINE Land Cover. This is because of the differences between the smallest units used in obtaining the CLC database changes 1990-2000 (5 ha) in the period 1990-2000 and the CLC databases in 1990 and 2000 (25 ha) and in the period 2000 to 2006 because of the processes of generalization of classes that have been applied in the methodology of obtaining the CLC2006 map. [Büttner 2004; IGN 2010]. Thanks to the matrix used, it has been possible to identify six processes in the study area along the urban-rural gradient [Anthrop 2006, Solon 2009; Van Eetvelde and Anthrop 2004]. Dynamic Process: This involves a change in land use between the classes identified in the second level of grouping (3 classes).

- *Rationalization:* Understood as the transformation of the Natural Landscapes (Rationalization I) or Traditional (Rationalization II) into Rational Landscapes. Essentially requires the input of anthropogenic energy for both processing and maintenance. Rationalization I requires more contribution than Rationalization II.
- *Agrarization:* Understood as the transformation of the Natural Landscapes (Agrarization I) or Rational (Agrarization II) into Traditional Landscapes. Requires the anthropogenic energy input in both transformation and maintenance. Agrarianization II processes require more energy input than Agrarianization I.
- *Renaturation:* Understood as the transformation of Rational Landscapes into Natural Landscapes. Requires anthropogenic energy input in transforming and natural energy on maintenance.
- *Abandonment-Naturalization:* Understood as the transformation of Traditional Landscapes into Natural Landscapes after ceasing anthropogenic energy. Its maintenance requires mainly the contribution of natural energy.
- *Exchange:* This involves a change in land use between classes belonging to the same class of second-tier level.
- *Permanence:* When there is no change in any grouping levels identified

2.2. Analysis of Spatial Patterns along the Urban-Rural gradient

Processes previously identified have been related into the transition matrices calculated for each sector, distance to the Spanish capital and for the period considered with the landscape patterns that have resulted, through the analysis of spatial indicators widely used in the characterization of the urban-rural gradient. These are able to characterize its heterogeneity in terms of Variety and/or Space Complexity. [Burel and Baudry 2002]. In the transition matrix the first level of aggregation (12 classes) was used. In the analysis of the evolution of spatial patterns the second level of aggregation (3 classes) has been used and that demonstrates more clearly the evolution the heterogeneity of landscape patterns along the urban-rural gradient. With the second-level group performed, the wide diversity of classes remains constant throughout the gradient – with the exception of some sectors in the Rational Landscapes disappearing in the area farthest from the capital - which facilitates the analysis of spatial heterogeneity and allows the use of Interspersion and Juxtaposition Index (IJI) which needs a minimum of three classes for its calculation. To perform an analysis of the evolution of each indicator in both longitudinal (distance to the Spanish capital) and transverse (timescale) all the values have been established with standard 100 mean, for each indicator analyzed.

Indicator		Range	Level C	Level L	Heterogeneity D	Heterogeneity R	Heterogeneity Ce
PERCENTAGE OF LANDSCAPE Percent area occupied by each type of landscape. It is a measure of dominance of the existing classes.	PLAND	0<PLAND ≤100	X			X	
NUMBER OF PATCHS Number of patches for each type of landscape	NM	NM ≥ 0	X				X
AVERAGE PATCH AREA Average size of the patches for each type of landscape	AREA	AREA ≥ 0	X				X
PATCH DENSITY Number of patches per 100 ha	PD	PD ≥ 0	X	X			X
EDGE DENSITY Is the total length of all edges exist, either for the whole class or landscape	ED	PD ≥ 0	X	X			X
LARGEST PATCH INDEX Percentage ratio between the area of the largest patch and the entire surface of the class analyzed or the total area (landscape scale)	LPI	0<LPI≤100	X	X			X
EUCLIDIAN MEAN NEAREST NEIGHBOR DISTANCE The shortest mean distance, measured in meters, between the centers of the patches of a particular class or all existing into a landscape.	ENN	ENN ≥ 0	X	X			X
MEAN FRACTAL DIMENSION Measures the complexity of the shape of the patches.	FRAC	1≤FRAC≤2	X	X			X
CONTAGION INDEX Measures the likelihood of adjacent pixels belonging to the same class	CONTAG	CONTAG ≥ 0		X			X
SHANNON DIVERSITY INDEX It is a measure of the variety of a landscape in terms of its diversity and its richness (Distribution of the proportion of classes that exist in a landscape)	SHDI	SHDI ≥ 0		X	X	X	
SHANNON UNIFORMITY INDEX Is the relationship between the current value of the Shannon Diversity Index and the maximum value attained if all patches occupied the same proportion in a landscape	SHEI	0 ≤SHEI≤1		X	X	X	
INTERSPERSION AND JUXTAPOSITION INDEX Measures the degree of adjacency (neighborhood) between classes or stains.	IJI	0<IJI≤100	X	X	X	X	X

C: Class. L: Landscape. D. Diversity. R: Richness. Ce: Complexity Space
[DiBari 2007; Dietzel et al. 2005; Solon 2009; Weng 2007; Zhang et al. 2004]
TABLE 2: Indexes considered

3. Results and Discussion

Dynamic processes identified in all the sectors did not exceed 4% of land area in any of the periods analyzed. In addition, all sectors have a similar relative proportion between the Permanence, the Exchange and the Dynamic Processes. Renaturation processes in all areas only affected the class "Other Rational Landscapes" which demonstrates the irreversibility of the rest of the classes identified, which even did not experiment exchange processes in the period. In the urban-rural gradient not only Rationalization processes were more intense in the vicinity of the Spanish capital, but also the processes of Abandonment and Renaturation. Considering the analyzed processes and relating them to spatial indicators used, the analyzed territory has not presented a significant variation of the variety or diversity in terms of class level or in terms of richness (in all sectors permanence is higher than 93%), so that the actual transformation results in the increased complexity of spatial patterns. Representing the value of each indicator by sector for each area of distance to the capital and year analyzed, with mean values typifying 100, has not only made possible the longitudinal analysis based on the distance to the Spanish capital, but also the cross-sectional analysis; that is how it has evolved the indicators for each distance to the capital and year.

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